REDUCTION OF NOx EMISSION IN DIESEL ENGINE USING EXHAUST GAS RECIRCULATION

A thesis submitted in fulfillment of the requirements for the degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

SUNIL KUMAR PANDA (108ME005)

Department of Mechanical Engineering

National Institute of Technology

Rourkela-769008

REDUCTION OF NOx EMISSION IN DIESEL ENGINE USING EXHAUST GAS RECIRCULATION

A thesis submitted in fulfillment of the requirements for the degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

SUNIL KUMAR PANDA (108ME005)

Under the guidance of

Prof.S.MURUGAN

Department of Mechanical Engineering

National Institute of Technology

Rourkela-769008

CERTIFICATE

This is to certify that the thesis entitled, "**Reduction of NOx emission in diesel engine using Exhaust Gas Recirculation** submitted by **Sunil Kumar Panda (108ME005)** in partial fulfillment of the requirements for the award of **Bachelor of Technology degree** in **Mechanical Engineering** at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma.

Date:

Prof.S.Murugan
Dept. of Mechanical Engineering
National Institute of Technology
Rourkela-769008

ACKNOWLEDGEMENT

I avail this opportunity to extent my hearty indebtedness to my guide "**Prof.S.Murugan**", Mechanical Engineering Department, for his valuable guidance , constant reinforcement and kind help at different stages for the execution of the dissertation work.

I am also grateful to **Mr.R. Prakash** and **Mr.N. P. Barik**, Mechanical Department for assisting me and guiding me throughout the project. I also extent my thanks to the supportive staffs of the Mechanical Department for providing me all the necessary facilities to accomplish this project.

Sunil Kumar Panda

(108ME005)

B.Tech

Mechanical Engineering

NIT Rourkela

ABSTRACT

Nowadays, internal combustion engines are the essential parts of transportation and mechanized agricultural system. So the consumption of diesel and petroleum has been upsurged. As petroleum is a nonrenewable source and recent surge in petroleum prices have regenerated interest in bio-fuels. It has shown that biodiesel-fueled engines produce less CO, unburned HC and smoke emissions compared to diesel fuel, but higher NOx emissions. Exhaust Gas Recirculation (EGR) is an efficient technique to reduce NOx emission as it lowers the flame temperature in the combustion chamber. The objective of this work is to reduce NOx emission from jatropha biodiesel fueled CI engine. A twin-cylinder, water cooled, constant speed direct injection diesel engine was used for this experiment. The content of HC, NOx, CO and smoke in the exhaust gas were measured to estimate the emissions. Application of EGR with biodiesel resulted in reductions in NOx emissions without any significant upsurge in smoke emissions. The graphs were plotted comparing the emissions from diesel fuel and jatropha biodiesel fuel with 0%, 5%, 10%, 15% EGR.

CONTENTS

LIST OF FIGURES

CHAPTER-1

INTRODUCTION

INTRODUCTION:

Petroleum fuel is a non-renewable source of energy. The petroleum reserves have been depleting and there is rise in petroleum prices. But there is an enormous upsurge in number of vehicles each year which has regenerated interest in alternative fuels. The biodiesel has emerged as alternative for diesel fuel due to its renewable nature, better ignition quality, comparable energy content, higher flash point. Biodiesel refers to a vegetable oil or animal fat-based diesel fuel consisting long chain of esters. It is made by chemically reacting the lipids with an alcohol producing fatty acid esters.

A lot of researches have been conducted on internal combustion engines using biodiesel fuel and it shows that the engines produce less carbon monoxide, smoke emissions and unburned hydrocarbon compared to diesel fuel but higher NO_x emission. Diesel engine combustion yields large amounts of NO_x because of high flame temperatures in presence of ample oxygen and nitrogen in the combustion chamber. Upsurged environmental concerns and tougher emission norms have led to the development of advanced engine technologies to reduce NO_x. Exhaust Gas Recirculation is one of the most efficient methods to decrease NO_x emission in diesel engine.

CHAPTER-2

LITERATURE SURVEY

Balusamy and Senthilkumar[1]: They have conducted an experiment using jatropha biodiesel in a fully automated single-cylinder, water-cooled, constant speed direct injection diesel engine. HC, CO, NO_x and smoke of the exhaust gas were measured. Various engine parameters such as thermal efficiency, and brake specific fuel consumption were accounted from the acquired data. Emission results have been compared with results that have been come from diesel fuel.

V.Pradeep and R.P.Sharma [2]: They have used HOT EGR technique for NO_x control in a compression ignition engine fuelled with bio-diesel from jatropha oil. A 3.75 kW single-cylinder, four stroke, water-cooled diesel engine is used. Emissions are measured and compared with diesel. Engine parameters such as brake thermal efficiency, brake specific energy consumption and combustion parameters such as cylinder pressure, rate of heat release, rate of pressure rise and combustion duration were measured at different stages.

Deepak Agarwal: He has made exploration of control of NO_x emissions biodiesel fueled CI engine and concluded that both NO_x and smoke can be reduced simultaneously only when engine run with biodiesel along with Exhaust Gas Recirculation system.

R.P.Sharma: NO_x content in the exhaust is higher in case of Jatropha Bio-diesel fuel compared to diesel fuel.

J Szybist and A K Agarwal: Inherent oxygen in JBD structure leads to higher NO_x formation.

J Szybist: Higher boiling point and bulk modulus of JBD leads to higher NO_x emission.

Ladommatos N, et al.[7]: Because of recirculation of exhaust gas into the cylinder thermal capacity of the intake charge upsurges leading to reduction of NO_x emission.

Avinash Kumar Agrawal, et al.[9]: They have conducted an experiment on a two-cylinder, direct injection, air-cooled CI engine to observe the effect of exhaust gas recirculation on the exhaust gas temperature and exhaust opacity.

K.Rajan and K.R.Senthilkumar: They have conducted experiment on the effect of exhaust gas recirculation on the performance and emission characteristics of diesel engine.

S.K.Mahla, L.M.Das, M.K.G.Babu[8]: They have conducted experiment to study the effect of EGR on performance and emission characteristics of natural gas fueled diesel engine. They used a single cylinder DI commercial diesel engine for the experiment.

T.K.Kannan, R.Marappan: They have done the experiment to study the performance and emission characteristics of a diesel engine.

CHAPTER-3

JATROPHA BIO-DIESEL

3.1 Features of Jatropha curcas:

- Jatropha curcas plant consumes less water and can grow in waste land.
- Its cultivation, seed collection, oil extraction and bio-diesel production can generate high-scale employment.
- The by-products that are generated during the production of bio-diesel can be used in fertilizer and soap industries.

It is not recommended to use vegetable oil directly in the diesel engine because it creates various long-term operational and durability problems such as poor fuel atomization, fuel injector choking, piston ring sticking, fuel pump failure, fuel filter clogging, and lubricating oil dilution.

3.2 Production of Jatropha bio-diesel:

Vegetable oils are triglycerides whereas bio-diesels are mono alkyl esters of long chain fatty acids derived from renewable fats such as oils and animal fats for use in CI engines. Transesterification is an effective process to produce bio-diesel from vegetable oil. Jatropha curcas oil is chemically reacted with methanol in the presence of a catalyst to produce jatropha bio-diesel (JBD). The catalyst that is generally used is sodium or potassium hydroxide.

$$C_6H_5O_6R_3 + CH_3OH \longrightarrow 3C_2H_3O_2R + C_3H_8O_3$$

(Glyceride) (Alcohol) (Methyl Esters) (Glycerol)

3.3 Properties of Jaropha Biodiesel:

- JBD is free from sulphur and still exhibits excellent lubricity.
- Its flash point and fire point are higher than diesel. So it is a much safer fuel than diesel.
- Presence of oxygen in JBD structure reduces energy content of fuel and also contributes to NO_x emission, but it also facilitates complete combustion, therefore reducing CO and HC emissions.
- Bulk modulus of JBD is higher than diesel fuel, which leads to rapid transfer of pressure from fuel pump to lift the needle of the injector much earlier. It results in more fuel accumulation before the start of combustion giving rise to higher peak temperature and subsequently higher NO_x.
- Boiling point of JBD is higher than diesel fuel. Because of higher boiling point, it retains its liquid state for a long duration.

Table-1. Properties of fuels used

PROPERTY	DIESEL	JO	JBD	ASTM CODE
Calorific Value (kj/kg)	43200	40148	40462	D4809
Specific Gravity	0.823	0.92	0.839	D445
Kinematic Viscosity	3.9	4.8	4.2	D2217
Cetane number	49	42	47	D4737
Color	Light Brown	Yellow	Light Yellow	D1500-2
Flash Point (°C)	56	128	110	D92
Fire Point (°C)	64	135	120	D92
Cloud Point (°C)	-8	-4	-6	D97
Pour Point (°C)	-20	-7	-8	D97
Ash Content (%)	0.001	0.003	0.003	D976

JO-Jatropha Oil

JBD-Jatropha Bio-Diesel

ASTM-American Standards for Testing and Materials

CHAPTER-4

EXHAUST GAS RECIRCULATION

4.1 Reactions involved in generation of NO_x:

Diesel engines function on lean mixture that is a high quantity of air is mixed with a low proportion of fuel. This associated with the high temperature in the combustion chamber leads to appearance of nitrogen oxide. These reactions take place at high temperature.

$$O+N_2 = NO+N$$

$$N+O_2 = NO+O$$

$$N+OH = NO+H$$

NO can further react to form NO_2 by various means.

$$NO+H_2O = NO_2+H_2$$

$$NO+O_2 = NO_2+O$$

Therefore, to reduce NO_x emission the peak temperature of engine cylinder must be lowered.

4.2 About Exhaust Gas Recirculation (EGR):

EGR is an effective technique to reduce NO_x formation in the combustion chamber. Exhaust mainly consists of CO_2, N_2 and water vapors. When a part of this exhaust gas is recirculated to the cylinder, it acts as diluent to the combustion mixture. It also reduces the O_2 concentration in the combustion chamber. Because of high specific heat of EGR, heat capacity of the intake charge upsurges, thus decreasing the temperature rise for the same heat release in the combustion chamber.

$$\% \, EGR = \frac{Volume\ of\ EGR * 100}{Total\ intake\ charge\ into\ cylinder}$$

The amount of EGR that is recirculated should be efficiently managed; otherwise it would lead to lower the efficiency of the engine.

Ignition delay, upsurged heat capacity and dilution of intake charge with inert gases are the three popular explanations for the effect of EGR on NO_x reduction. EGR causes an upsurge in ignition delay which is equivalent as retarding the injection timing. The heat capacity hypothesis asserts that addition of exhaust gases into the intake charge upsurges the heat capacity which lowers the peak combustion temperature. According to the dilution theory, increasing amount of inert gases in the mixture reduces the adiabatic flame temperature thus reducing NO_x formation inside the chamber.

4.3 Classification of EGR systems:

Classification Based on temperature:

- Hot EGR: Exhaust gas is recirculated without being cooled which results an upsurged intake charge temperature.
- Fully Cooled EGR: Exhaust gas is fully cooled before mixing with fresh intake air using water cooled heat exchanger.
- Partly Cooled EGR: The temperature of the exhaust gas is just kept above its dew point temperature to avoid water condensation.

Classification Based on Configuration:

- Long Route system (LR): In LR system, the pressure drop across the air intake and the stagnation pressure in the exhaust gas stream make the EGR possible.
- Short Route System (SR): These systems differed mainly in the method used to set up a positive pressure difference across the EGR circuit.

Classification Based on Pressure:

- Low pressure route system: The passage for EGR is provided from downstream of the turbine to the upstream side of the compressor. It is found that by using the low pressure route system, EGR is possible up to a high load region with significant reduction in NO_x.
- High pressure route system: The EGR is passed from the upstream of the turbine to downstream of compressor. In this method, although EGR is possible in high load regions, the excess air ratio decreases and fuel consumption upsurges remarkably.

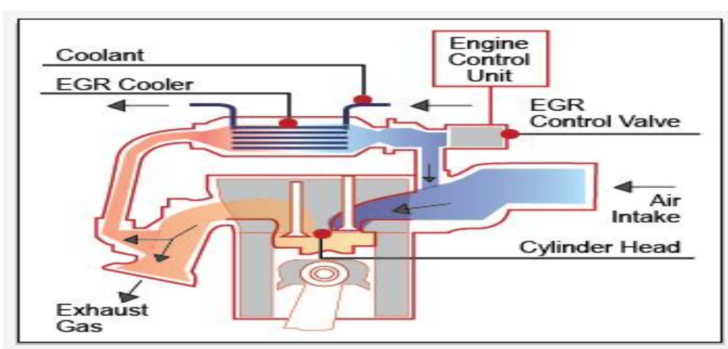


Fig.1 EGR System

CHAPTER-5

EXPERIMENTAL SETUP

AND

METHODOLOGY

5.1 ENGINE SPECIFICATIONS AND APPARATUS:

Comet diesel engine,

Twin cylinder,

Vertical water cooled,

7.5 KW @ 1500rpm.

Compression ratio = 17.5

Eddy current dynamometer

Fuel measuring device

Stop watch scale and

Spring balance.

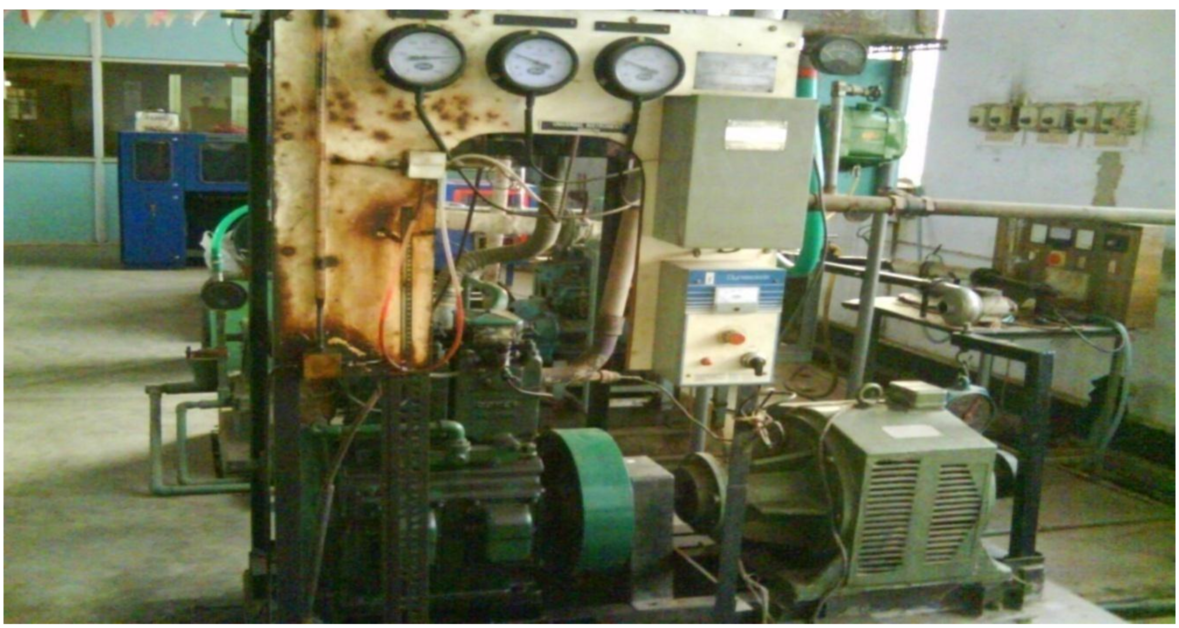


Fig-2 Photographic View of Experimental Setup

5.2 PROCEDURE:

1. The filters of the engine were replaced and the injectors were cleaned and calibrated according to the desired pressure.

2. The AVL gas analyzer and smoke meter were installed. The input to the gas analyzer was taken from the exhaust port of the engine.

3. The fuel tank was then filled with diesel and the engine was run.

4. The engine was run at various loads of the dynamometer – 5, 10,15,20,25 kgs and respective readings were taken for fuel consumption/ sec.

5. The readings of gas analyzer and smoke meter were noted in each case.

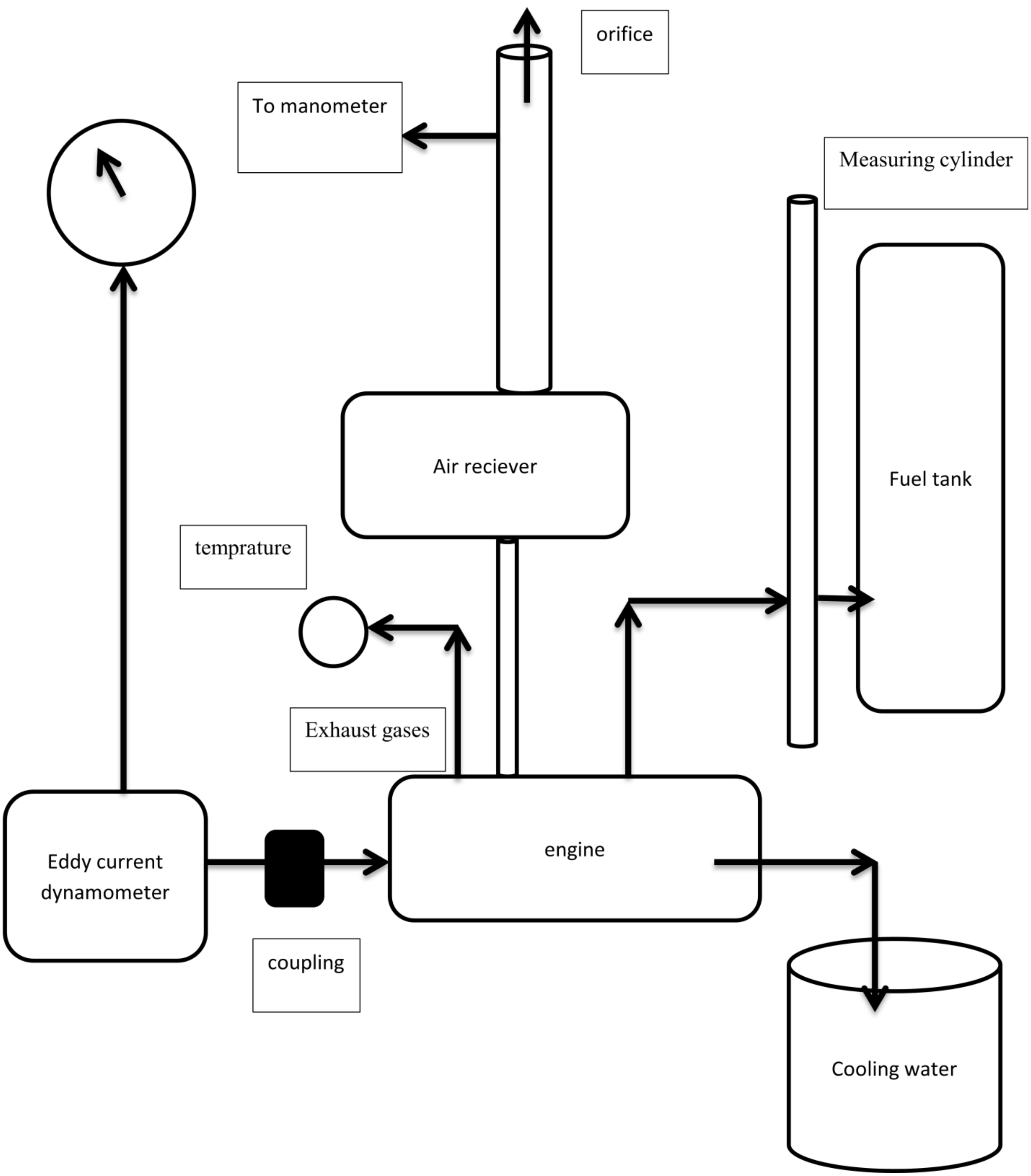
6. After all the readings were taken, the leftover diesel was drained out of the tank and Jatropha bio-diesel (B100) was poured.

7. Same steps were taken and the readings were noted down for the bio-diesel.

8. Then the engine was run with 5%, 10%, 15% EGR at various loads of the dynamometer and the reading were taken.

9. After taking all the observations, graphs were plotted to compare the performance characteristics and emission characteristics of the engine in case of diesel and jatropha bio-diesel with 0%, 5%, 10%, 15% EGR.

Schematic diaram of the set up:



CHAPTER-6

CALCULATION

6.1 Brake Power Calculation:

B.P= 2*π*N*T/60000 (kW)

Where T= S*R

N=rpm of the engine=1500

R=17.5 cm

S= Spring Balance

At S=5kg $\longrightarrow$ B.P= 1.347 kW

S=10kg $\longrightarrow$ B.P= 2.694 kW

S=15kg $\longrightarrow$ B.P= 4.041 kW

S=20kg $\longrightarrow$ B.P= 5.388 kW

6.2 Brake Specific Fuel Consumption (BSFC):

$$BSFC= \frac{Vol.of\ fuel*density}{\mathrm{B.P*time}}$$

$$BSFC= \frac{20\ c.c.of\ fuel*density}{\mathrm{B.P.*time\ taken\ for\ 20\ c.c.to\ consume}}$$

6.3 Brake Specific Energy Consumption (BSEC):

BSEC= Calorific Value of Fuel * BSFC

CHAPTER-7

RESULTS AND DISCUSSION

7.1 Nitrogen oxide (NO_x) Emission:

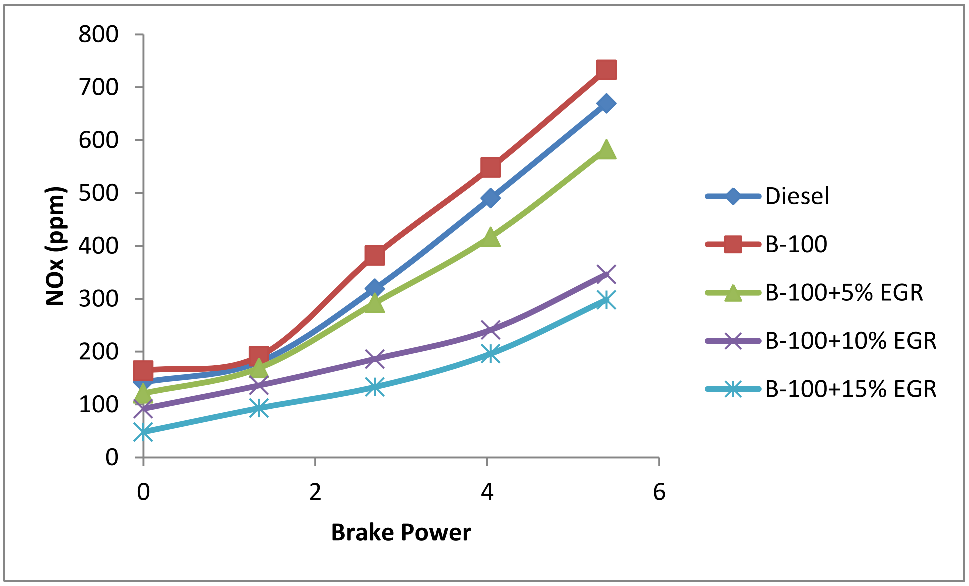


Fig-4 NO_x emission vs. Brake Power

Fig-4 shows variation of NO_x emissions with brake power from diesel engine. The emission is higher in case of jatropha bio-diesel compared to diesel because of high flame temperature in presence of ample nitrogen and oxygen. When EGR is applied, NO_x emission is decreased with upsurged EGR rates. The reason behind this is, reduced oxygen concentration because of dilution of intake charge and decreased flame temperature. The EGR rate cannot be upsurged beyond the limit as thermal efficiency will decrease in a high rate. At the maximum load, NO_x emission level for 5% and 10% were found to be 20.4% and 52.7% decreased respectively than that of without EGR.

7.2 Hydrocarbon (HC) Emission:

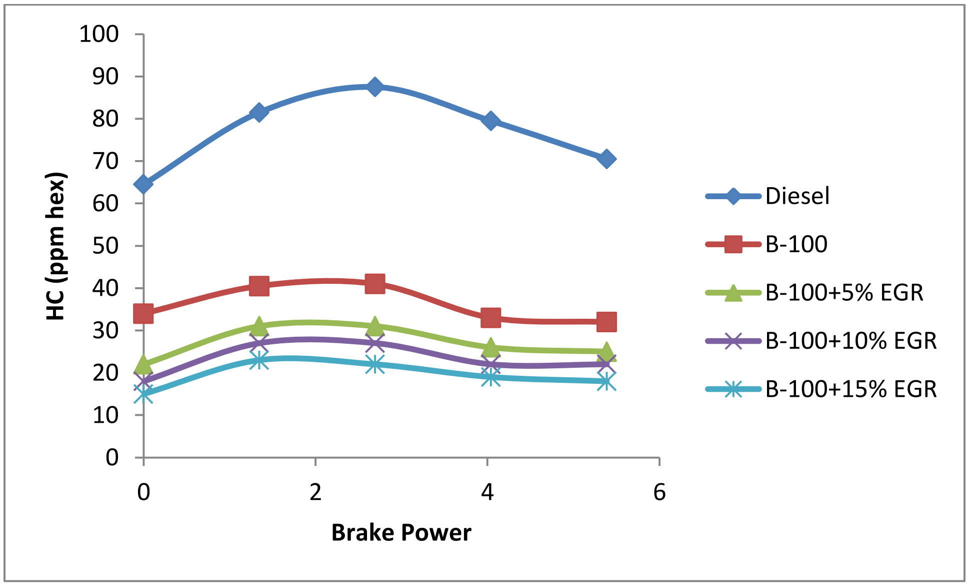


Fig-5 HC Emission vs. Brake Power

Fig-5 shows that HC emission is lower in case of Jatropha bio-diesel and bio-diesel employed with EGR compared to diesel because of efficient burning. There is 43.75% of reduction in HC emission in case of 15% EGR at the maximum load.

7.3 CO Emission:

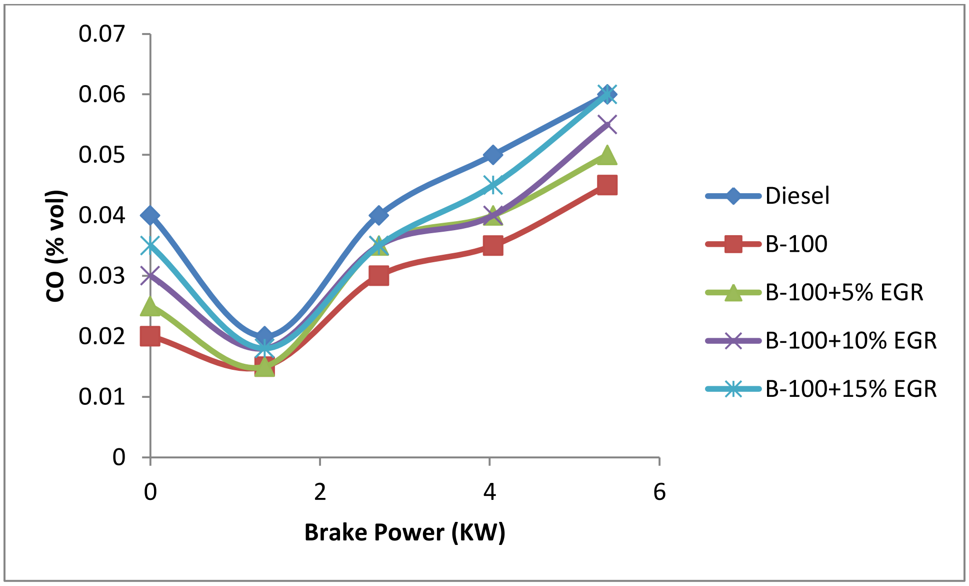


Fig-6 CO Emission vs. Brake Power

There is a decrease in CO emission in JBD compared to diesel fuel. After using EGR, there is an increase in CO emission because of decreasing air-fuel ratio. The increase of CO emission incase of 5%, 10%, 15% EGR are 11.11%, 11.22%, 33.33% respectively.

7.4 CO_2 Emission:

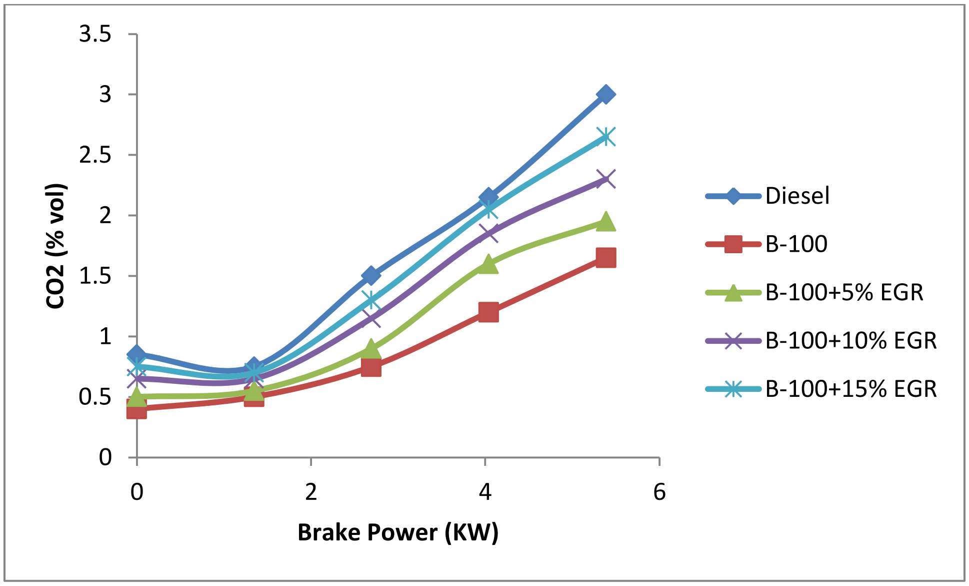


Fig-7 CO_2 Emission vs. Brake Power

There is a decrease in CO_2 emission in JBD compared to diesel fuel. After using EGR, there is an increase in CO emission because of decreasing air-fuel ratio. The increase of CO emission incase of 5%, 10%, 15% EGR are 18.18%, 39.39%, 60.60% respectively.

7.5 Brake Specific Fuel Consumption (BSFC):

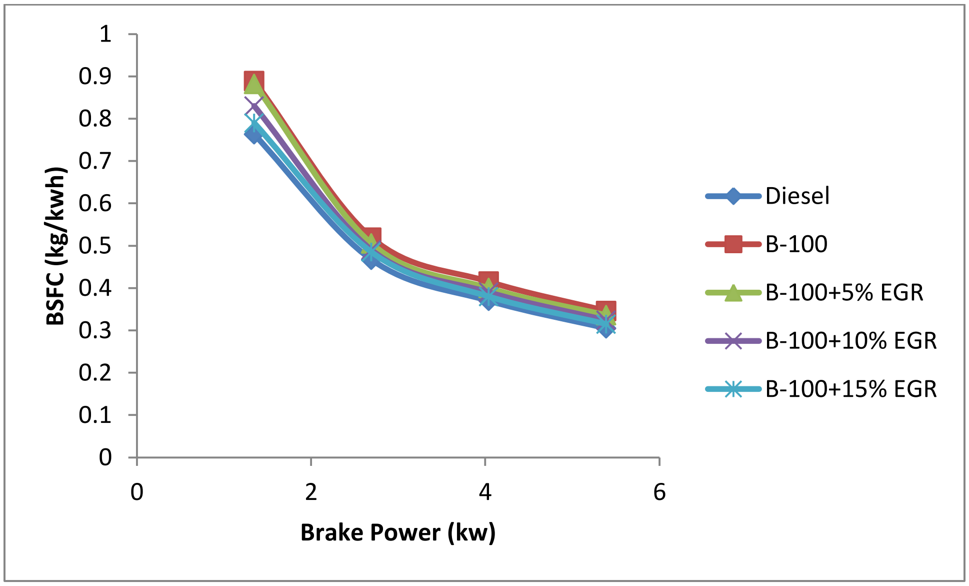


Fig-8 BSFC vs. Brake Power

Fig-8 shows the nature of bsfc for bio-diesel fueled engine with/without EGR. For diesel, bsfc is lower at all loads for engine operated without EGR compared to engine was operated on biodiesel with and without EGR. This upsurge in bsfc was due to lower calorific value of biodiesel compared to diesel.

7.6 Brake Thermal Efficiency:

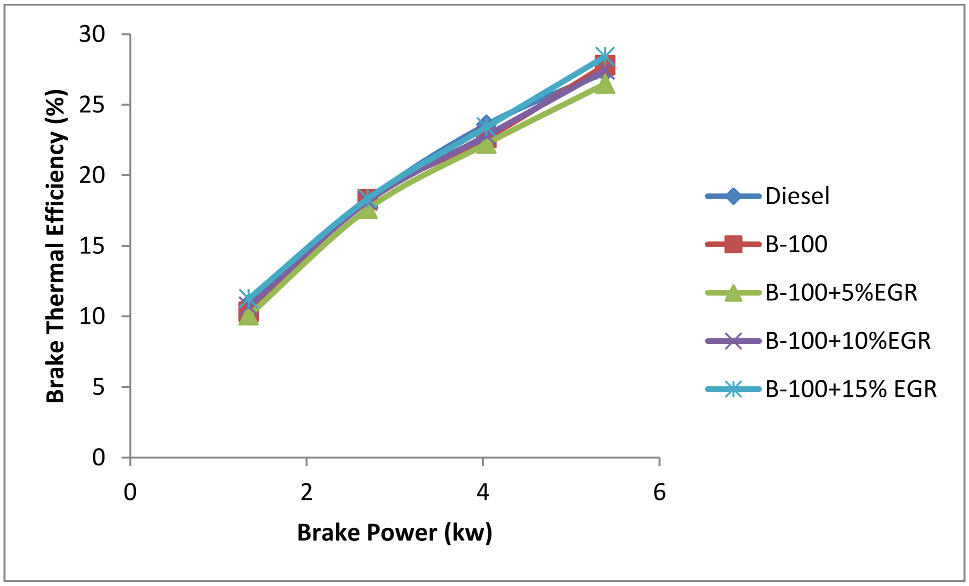


Fig-9 Brake Thermal Efficiency vs. Brake Power

Fig-9 represents comparison of brake thermal efficiency of biodiesel fueled engine with or without EGR. Thermal efficiency is found to be slightly upsurged with EGR at all level of engine loads. At the maximum load for 15% EGR, thermal efficiency is upsurged to 2.2%.

7.6 Conclusion:

- The higher NO_x emission can be effectively controlled by engaging EGR.
- Biodiesel and EGR both can be employed together in diesel engine to obtain NO_x reduction.
- 15% EGR is found to be optimum, which improves the thermal efficiency as well as reduces the exhaust emissions and BSFC.
- EGR upsurges the HC and CO emissions. Also, higher BSFC and particulate emission are observed.

Therefore, it was concluded that engine operation with Jatropha biodiesel while engaging EGR results in NO_x reductions without compromising engine performance.

References:

[1] Balusamy T. and Senthilkumar T. Reduction of NO_x emissions in Jatropha seed oil-fueled CI engine, vol.6, NO.5. May 2011

[2] Sharma RP. Bio-diesel and E-diesel in transportation—an OEM perspective. In: Proceedings of XVIII National Conference on IC Engines, Trivandrum, December, 2003, p. 539–50.

[3] Chairman, Committee on development of bio-fuel. Report of committee on development of bio-fuels. Planning Commission, Government of India, April 2003.

[4] Agarwal AK, Das LM. Bio-diesel development and characterization for use as a fuel in CI engines. ASME Trans 2001;123:440–7.

[5] Senthil Kumar M, Ramesh A, Nagalingam B. Explorations on the use of Jatropha oil and its methyl ester as fuel in a CI engine. J Inst Energy 2001;74:24–8.

[6] Senatore A, et al. A comparative analysis of combustion process in DI diesel engine fueled with biodiesel and diesel fuel, 2000, SAE Transaction 2000-01-0691. p. 1–11.

[7] Ladommatos N, Abdelhalim SM, Zhao, Hu Z. The effects of CO2 in EGR on diesel engine emissions. Proc Inst Mech Eng 2000;212(Part D):25–42.

[8] S.K. Mahla , L.M. Das , M.K.G. Babu . Effect of EGR on Performance and Emission Characteristics of Natural Gas Fueled Diesel Engine ISSN 1995-6665 Pages 523 – 530

[9] Avinash Kumar Agarwal and et al.:. Effect of EGR on the exhaust gas temperature and exhaust opacity in compression ignition engines Vol. 29, Part 3, June 2004, pp. 275–284

[10] Naik SN, Meher LC, Vidya Sagar D. 2006. Technical aspects of biodiesel production by transesterification - A review. Renewable and Sustainable Energy Reviews. 10: 248-268.

[11] Ramadhas AS, Jayaraj S, Muralidharan C. 2004. Use of vegetable oils as IC engine fuels- A review. Renewable Energy. 29: 727-742.

[12] Barnwal BK, Sharma MP. 2005. Prospects of biodiesel production from vegetable oils in India. Renewable and Sustainable Energy Reviews. 9: 363-378.

[13] Shailendra Sinha, Avinash Kumar Agarwal. 2005. Combustion characteristics of ricebran oil derived biodiesel in a transportation diesel engine. Society of Automotive Engineers. 26: 354.

[14] Suryawanshi JG, Despande NV. 2004 Experimental explorations on a pungamia oil methyl ester fuelled diesel engine. Society of Automotive Engineers. 28: 18.

[15] Naveen Kumar, Abhay Dhuwe. 2004. Fuelling an agricultural diesel engine with derivative of palm oil. Society of Automotive Engineers. 28: 39.

[16] Nagaraja AM, Prabhukumar GP. 2004. Characterization and optimization of rice bran oil methyl ester for CI engines at different injections pressures. Society of Automotive Engineers. 28: 0039.

[17] John B Heywood. 1988. Internal Combustion Engine Fundamentals. Automotive Technology Series (McGraw-Hill International Editions), Singapore.

[18] 1994. Annual Book of ASTM Standards (American Society for Testing and Materials, Philadelphia).

[19] http://www.tc.gc.ca/eng/programs/environment-etv-egr-eng-1144.htm